Main Injector 8 GeV Beam Line Shielding Assessment

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Attachment G	Radiation Dose on the 8 GeV Beam-line Berm due to Sight Riser, C. M. Bhat (Feb. 14, 1997).
Attachment H	Shielding Requirements Around the Intersection of AP2 and 8 GeV Beam Lines", by C.M. Bhat (April 7, 1994).
Attachment I	Radiation Level in the Intersection Region of AP2 and 8 GeV Beam-line, Due to Beam loss in the AP2 Beam-line", C.M. Bhat and P. Martin (1995).
Attachment J	"Temporary, Partial Transport Enclosure Shielding Assessment and Suggested Entry Controls to Permit Personnel Access to the MI-8 Enclosure During Transport Beam Operations" , Memo from Tony Leveling to R. Pasquinelli, Dated Nov. 1 1996.

I. Introduction

The 8 GeV beam line tunnel consists of a remnant of the AP4 line (location 800 to 803) and of a newly built enclosure (locations 803 to 850) with a total length of about 2600 ft [1,2]. For purposes of this assessment, location 803 is defined as the point between 803 and 804 where new civil construction began, that is, just downstream of the AP4 dump. A plan view of the beam line is shown in drawing 6-6-12 SC-1. The 8 GeV beam line site plan and its cross sections are shown in drawings 6-6-9 C3 (also see drawing 6-6-9 C11) and 6-6-9 C4, respectively.

Since this beam line consists of existing and new construction, a multi-faceted approach to the shielding assessment is necessary. The new construction passive shielding was designed and built specifically for the Main Injector operation. The remnant, existing structure which includes locations 800 through 803 was originally designed for lower intensity operation. Due to the proximity of the West Booster Tower, the feasibility of placing additional shielding above the remnant enclosure was uncertain and the cost of doing so was prohibitive.

It will be shown that the shielding adjacent to locations 800 to 803 is the only above-ground region covered by this shielding assessment with less than 24.5 ft of soil equivalent shielding. Historically, control of radiation levels in and adjacent to the building due to extraction beam losses has been controlled with a combination of interlocked detectors, radiological postings, and occupancy limitations. During Main Injector era it will be necessary to follow similar control procedures.

A number of plans have been considered to compensate for the deficiency in the passive shielding [3, Attachment A]. However, at the time of this writing, a separate assessment of the 800 through 803 location is planned to be performed in conjunction with commissioning and startup of the MI8 line. In this separate assessment, an appropriate combination of interlocked detectors, access controls, radiological postings, and occupancy limitations will be sought which meet the requirements of the Fermilab Radiological Controls Manual [4]. Hence, no conclusions will be made regarding the adequacy of shielding for the 800 to 803 location in this assessment.

a) Basic Shielding Requirement for MI8 Line

The Main Injector preliminary Safety Analysis Report [5] specifies that a minimum of 24.5 ft soil equivalent shielding is required over the 8 GeV beam line enclosure to establish unlimited occupancy for both accidental as well as normal operational beam loss conditions. This specification was derived from the Dugan Criteria [Ref. 6, i.e., Attachment -B] and applies to all locations along the tunnel where disturbances in the passive shielding do not exist. The radiation shielding drawings included in Section V B indicate that the requirement of 24.5 ft soil equivalent shielding is met at almost all locations along the 8 GeV beam line enclosures.

b) Analysis Requirements for Disturbances in Passive Shielding

Regions in which passive shielding is disturbed by exit stairways and labyrinths, drop hatches, cable penetrations, site risers, the transport enclosure overpass, shielding media and enclosure step changes, and other such features cannot be analyzed by simple review of basic shielding criteria. These disturbances require special analysis [7-10] and are discussed below. The drawings shown in Section V B represent the conditions at present and the shielding is adequate for low intensity commissioning runs. For high intensity operations (see Table I) additional shielding will be placed.

c) Radiation Safety Requirements

The shielding criteria [5] were developed in 1991 in accordance with the Fermilab Radiation Guide. Since that time, the Guide has been renamed as the Fermilab Radiological Controls Manual (FRCM), and the Radiation Guide tables [Ref. 11, Attachment-C] which contained dose rate, occupancy, and posting requirements for normal and accident conditions used at that time have been revised. For purposes of this assessment, the revision in the tables did not affect the accident condition shielding design for locations 803 to 850 since the "no occupancy limit" entries have remain unchanged. The normal condition FRCM requirements have changed. However, based upon normal operational losses cited in Table II below, it is concluded that normal losses will be unmeasureable, thereby meeting the normal condition FRCM requirement for unlimited occupancy.

The requirements for the 800 to 803 regions are affected by the revised tables. The requirements of the current FRCM tables will be applied for the assessment of the 800 to 803 locations. Since it is likely that the tables will change with the next FRCM revision, they are reproduced here as Exhibit I, II, and III for convenience of initial and future reviewers.

Exhibit I

TABLE 2-5 Control of Outdoor Accelerator/Beamline Areas Against "Normal" Radiation Levels

Dose Rate	Level of Precaution
DR < 0.025 mrem/hr	No precaution needed, no occupancy limit
0.025 < DR < 0.25 mrem/hr	Signs, ("Caution--Controlled Area")--no occupancy limit
0.25 < DR < 5 mrem/hr	Signs, ("Caution--Controlled Area")--minimal occupancy
5 < DR < 10 mrem/hr	Signs with chains and/or fencing to define the perimeter ("Radiation Area"), area must have minimal occupancy.(On a temporary basis, ropes may be substituted for fences/chains.)
10 < DR < 100 mrem/hr	Signs ("Radiation Area") and fences with locked gates. For beam-on radiation, access is restricted to authorized personnel only.
100 < DR < 250 mrem/hr	Signs ("High Radiation Area"), 8 ft. high fences with locked gates the keys to which are interlocked. Fences with no gates are a permitted alternate. No beam-on access permitted.
250 < DR < 1000 mrem/hr	Signs ("High Radiation Area"), 8 ft. high fences with locked and interlocked gates and visible flashing lights warning of the hazard. No beam-on access permitted.
DR > 1000 mrem/hr	Not Allowed

Exhibit II

Table 2-6A Control of Outdoor Accelerator/Beamline Areas Against Accident Radiation Levels: Radiation Interlocks not Used

Maximum Dose Equivalent per One Hour (D)	Level of Precaution
D < 1 mrem	No precaution needed, no occupancy limit
1 < D < 5 mrem	No precaution needed, area must have minimal occupancy
5 < D < 100 mrem	Signs ("Radiation Area")with chains and/or fencing to define the perimeter, area must have minimal occupancy. (On a temporary basis, ropes may be used in place of chains.)
100 < D < 500 mrem	Signs ("High Radiation Area") and fences with locked gates. Access by authorized personnel only
500 < D < 1000 mrem	Signs ("High Radiation Area") and fences with interlocked gates and visible flashing lights warning of the hazard. Fences with no gates are a permitted alternate. No beam-on access permitted.
D > 1000 mrem	Not Allowed

Exhibit III

Table 2-6B Control of Outdoor Accelerator/Beamline Areas Against Accident Radiation Levels: Radiation Interlocks Used

Maximum Dose Equivalent, D, /Interlock Trip (mrem) and Maximum Allowed Dose Equivalent in One Hour, DR (mrem/hr) limited by the Number of trips Permitted.	Level of Precaution
D < 0.25 mrem and DR <1 mrem/hr	No precaution needed, no occupancy limit
0.25 < D < 5 mrem/hr and DR < 10 mrem/hr	No precaution needed, area must have minimal occupancy
5 < D < 10 mrem and DR < 100 mrem/hr	Signs ("Radiation Area") with chains and/or fencing to define the perimeter, minimal occupancy (on a temporary basis ropes may be used in place of chains)
10 < D < 50 mrem and DR< 500 mrem/hr	Signs ("High Radiation Area") and fences with locked gates. Access by authorized personnel only.
50 < D < 250 mrem and DR < 1000 mrem/hr	Signs ("High Radiation Area"), 8 ft. high fences with locked gates whose gate keys are interlocked. Fences with no gates are a permitted alternate. No beam-on access allowed.
D > 250 mrem	See Article 238.4 (Special Circumstances)

d) Beam Intensity Limits

The total beam intensity to be transported through the 8 GeV beam line is based upon the design capability of the Main Injector operation cycles and the beam used by the high energy physics experiments. The Main Injector has five different types of operation cycles with one mixed mode [2]. The scenarios of Main Injector operation and the design beam intensity in each of these cycles are shown in Table I. The 8 GeV beam intensity transported per hour through the beam line is maximum for NUMI operation.

Table I

Main Injector Operation Cycles and Beam Intensities[1]

Operation Mode	Number of Booster Batches	Energy	Cycle (sec)	Flattop (sec)	Proton/cycle
Antiproton Production	1	120 GeV	1.5	0.04	5E12
Fixed Target Injection	6	150 GeV	2.4	0.25	3E13
Collider Injection	1	150 GeV	4.0	1.45	5E12
High Intensity slow spill	6	120 GeV	2.9	1.0	3E13
High Intensity fast spill (NuMI Intensity)	6	120 GeV	1.9	0.04	3E13

Table II

8 GeV Beam Losses[5]

Category	Protons	
Operational Losses	1.0 E19/year	1.67E15/hour
Accidental Losses	5.7E16/Accident	5.7E16/Accident

From past experience with the operation of the accelerator complex, an average annual operational beam loss and beam losses per accident are projected for Main Injector operational conditions. These losses include beam losses at extraction, injection and beam scraping etc. The expected beam loss in each of the two categories is listed in Table II. In the case of operational beam loss, the beam losses are distributed throughout the accelerator with relatively larger losses near extraction and injection sections. However, in estimating radiation shielding we are required to assume [4] that the maximum beam power loss may occur at any point near the region of interest for a period of one hour. The Dugan criteria is based upon such a loss at NUMI operating intensity. Other disturbances in the shielding are also evaluated using this conservative accident scenario.

II Radiation Shielding of the Beam Line

a) Booster Beam Extraction Region Between Locations 800 and 803

As mentioned earlier, this part of the MI8 line is to be evaluated under a separate assessment. This assessment is to occur immediately after low power startup and commissioning the MI8 line. Additional information on this is given in Ref. 12 [Attachment-D and Ref. 3].

b) Beam Line in the Region Between 803 to 810

The geometry of the beam line tunnel from location 803 to 810 is very complicated. Plan, elevation, and cross section views of this region are shown in drawings 6-6-12 C-22 and 6-6-12 C-23. Extensive shielding depth evaluations were carried out with 3D ray tracing computer codes [9] and also with CASIM [7]. Through these evaluations, available in a separate folder [13], we have determined the shielding "deficits"[@] . Additional shielding thickness has been provided by using steel absorber in addition to earth.

The calculations of the amount of steel required in those areas where there was insufficient earth shielding were generally done twice; P. Martin used an EXCEL spreadsheet, written with the full geometry of the tunnel enclosure, beam elevation, berm geometry and up to eight blocks of steel. This spreadsheet could

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[@] the "deficit" is defined as the difference between the measured thickness of the soil and the required soil equivalent thickness in that direction.

be used to rather quickly determine the approximate steel dimensions of each layer, and then calculate through a fairly coarse two-dimensional matrix of loss points along the beam vs. azimuthal angle, with a one-dimensional polar angle array being calculated for each point in the matrix. The steel dimensions were then increased if any deficits were found. The geometry was then given to C. Bhat, who used a FORTRAN program [9] to check the results, with somewhat finer resolution in the loss coordinates and angles. Both of these programs were ray-tracing, i.e. they calculated the amount of shielding along a vector in space. Considerable effort in developing these programs went into correctly formulating the equations for determining the path length through the steel, especially as the vector is moving past the edge of the steel in one coordinate or the other.

In both cases, the following assumptions were made. First, it was assumed that one foot of steel was equivalent to 2.89 feet of soil [14]. In that reference, it is shown that the soil-equivalency of steel depends upon the star density in the shower; the value 2.89 feet lies in the middle of the range. Second, it was assumed that the desired amount of shielding depends upon the polar angle of the point on the surface relative to the loss point [9]. The peak of the star densities vs. radial distance in CASIM calculations occurs at around a 70 degree angle measured from the beam direction (or 20 degrees relative to the radial direction). Fitting the density vs. angle for the isodose contour corresponding to the allowed dose yielded the formula for the desired shielding (in feet) of 22 plus 0.2 times the angle (in degrees) relative to the radial direction. As an example, this formula requires 26 feet of shielding at an angle of 20 degrees. Note that this also agrees with the Dugan criteria which were formulated for uniform shielding topology: 24.5 feet divided by the cosine of 20 degrees gives 26 feet. It is important to note that in non-uniform geometries such as we are considering here, to use 24.5 feet as a thickness at all angles would greatly under-shield in the forward direction, and would over-shield at 90 degrees and in the backward direction.

c) Beam Line in the Region 810 to 850

The beam line in this region is typically at an elevation of 715.8 ft with the enclosure ceiling at 721.5 ft. The surface berm elevation is no less than 746 ft, hence total soil thickness is 24.5 ft. Local disturbances in the typical configuration are evaluated separately in following sections.

d) Exit Stairs and Penetrations

There are five exit stairs in the 8 GeV beam line; these are needed to comply with Life Safety Code requirements. They are at approximate locations 808, 818, 828, 842, and 852. Four of the five exit stairs have similar structures (drawings 6-6-9 SC-13 and SC-14); the one near location 808 is unique (drawings 6-6-9 SC-2 and SC-8). We have estimated the radiation dose near both types of exits at the surface using EXIT2A [10]. Independent of this, we have also used the ray tracing program [9] with exact geometry for each exit stairs and surrounding area to find out whether there is sufficient shielding. Where deficits in the original design were found, recommendations were made for changes in the design of the exit stairs. Thus the expected radiation dose near the exits at surface level in the worst case accident scenario meet or are below that required for unlimited occupancy (see Table III).

The utility penetrations at service buildings are also of concern from the radiation dose point of view. There are two types of utility penetrations in the MI-8 service building (drawing 9-6-6-9 C-4). One type consists of straight, 45-foot long, 8-inch diameter penetrations. The second type consists of three legs of 6-inch diameter conduit with a total length of approximately 55-feet. There are 24 penetration conduits separated by a minimum distance of 2.25 ft. The estimated radiation levels in the MI-8 service building arising from these penetration are also listed in the Table III.

Air exhaust ventilation ducts (2-foot diameter) are provided at alcoves in the beam line. A drawing of a typical ventilation duct is shown in 6-6-9 M4. The radiation levels at the surface level near the exhaust are found to be well below FRCM limits (see Table III).

Table III.

Estimated Radiation Dose Near Exit Stairs and Penetrations

Location	Radiation Dose	
	Normal Beam loss (mrem/ hr)	Accidental Beam loss (mrem/ accident)
Near Exit door at the surface	<0.025	<0.1
Near far end of straight penetrations (8 in dia)	0.03	1.0
Near far end of the bent penetrations (6 in dia)	<<0.025	<<1.0
Near far end of the air exhaust penetrations	<<0.025	<<1.0

e) MI-8 Service Building

The MI-8 service building is the only service building on the 8 GeV transfer line. The drawings 6-6-9 SC-7, SC-8 and SC-9 show plan and section views of the alcove, labyrinth, indoor hatch and stairs in this building. To estimate the radiation dose level in the building we use results of Monte Carlo calculations in combination with results of EXIT2A. The estimated radiation dose under the shielded hatch from CASIM is 3.2 $\times 10^{-18}$ rem/proton lost in the beam line. The expected radiation level near the elevator, the top of the hatch, and the top of the stairs are listed in Table IV. The expected radiation levels above and below the hatch listed in Table IV exceed those permitted for unlimited occupancy. However, once the MI 8 Service Building becomes operational, it will be used to store radioactive components, a condition which will require it to be posted as a Controlled Area and locked with a key/core system used for similar existing service buildings. In addition, the region beneath the drop hatch will be posted as a radiation area and will be interlocked to preclude personnel access while beam is operable in the MI 8 line. Adoption of the interlocks, radiological postings, and access controls will be used to ensure that applicable requirements of the FRCM are met [Ref. 15, Attachment-E].

Table IV.

Estimated Radiation Dose Near MI 8 Service Building

Location	Radiation Dose	
	Normal Beam loss (mrem/ hr)	Accidental Beam loss (mrem/ acci-dent)
Bottom of the hatch North entrance -A	5.4	182
With 1.5 ft Concrete shielding on the Hatch	0.069	2.3
Below the hatch East entrance - B	0.25	8.4
Location - C	0.062	2.1
Location - D	0.042	1.4
Near the elevator - E	<0.025	<0.1
In the Service Building (top of the exit stairs)	<0.025	<0.1

f) 8 GeV Shielded Hatch

The beam line has a shielded hatch at location 817 for equipment drops. The soil shielding around this hatch is 24.5 ft except near the down stream end of the hatch. In this region the soil shielding is only 22.5 ft with about 2 ft of soil deficit. To improve the shielding, we have added steel. The details of this is shown in reference 16 [Attachment-F].

g) Sight Riser (survey points)

There are four sight riser along the 8 GeV beam line viz., at locations 812, 816, between 833 and 834 and one at AP2 and 8 GeV crossover. The last one is a penetration through the shielding steel above the 8 GeV beam line tunnel as well as the AP2 beam line tunnel. All of these are holes of 1-foot diameter at the most. These survey penetrations are potential shielding deficit points. In the case of the sight riser at the AP2/8 GeV crossover the contribution to the radiation coming from the AP2 and AP3 beam line losses have also been taken into account.

We have estimated the radiation level at the surface level from each one of these sight risers using EXIT2A [10] and confirmed the estimate with CASIM calculations. The radiation level is found to be as high as 2.5 mrem/hr from normal operational beam losses and ~100 mrem from accidental beam losses [Ref. 17, Attachment-G]. Hence these penetrations will be filled with a suitable shielding material (steel and concrete, polyethylene beads, or non-silica sand) to reduce the radiation levels to below those which permit unlimited occupancy.

h) Intersection of the 8 GeV Beam Line and AP2 Beam Line

Drawings 6-6-10 C-1 and 6-6-10 C-3 display the region between 830 and 831 where the 8 GeV beam line crosses below the AP2 beam line enclosure. These beam lines are at an angle of 49° with 4.5 ft of shielding in between. Over the AP2 beam line tunnel there is only 13 ft soil equivalent shielding resulting in a 7-foot of soil equivalent shielding deficit over the 8 GeV beam line at the intersection [18, Attachment-H]. Hence we have added 3.75 ft of steel (see drawings 6-6-10 C-3 and 6-6-10 C-5) which provides an soil equivalent shielding of 24.5 ft.

Operationally, a special precaution will need to be taken in this region [19, Attachment I, Ref. 20, Attachment-J]. Whenever there is beam in the 8 GeV line, considerable radiation levels could occur in the AP2 line tunnel. Consequently to have beam in the MI-8 line, one requires a transport radiation safety system permit which prohibits any personnel to be in the AP2 beam line tunnel.

A less significant radiation hazard may exist in the 8 GeV line between locations 830 and 831 while beam is transported through the Transport Enclosure [19]. An interlocked detector has been installed and a set of entry controls has been established and will be maintained to limit this hazard to levels permitted by the FRCM [Ref. 20, Attachment-J].

i) Manholes and Utility Ducts

Two manholes and two utility ducts are located near the intersection of the 8 GeV line and South Booster Road. To provide enough shielding to the electric manhole between location 807 and 808, an additional two layers of steel (i.e., 1.5ft of steel) was placed as shown in shown in drawing 9-6-6-12 C-4. The hand stacked concrete inside the corner of MH14 is also shown. The other manholes for the gas valve box and the two utility ducts are not of concern because they are sufficiently shielded.

III. Radiation Dose from the Muons in the 8 GeV Beam Line Tunnel

Muons produced as a result of 8 GeV proton beam on the beam line components have been considered. In the locations 804 through 850 it is not possible for muons to exit in to uncontrolled areas adjacent to the beam line since the proton beam is steered either horizontally or vertically downward. However, the produced muons will travel directly ahead and will be having an energy range up to 8 GeV. The range of the maximum energy muons in the soil is estimated to be about 100 ft. The plan view of the MI-8 GeV beam line enclosure (6-6-12 SC-1), also showing the MI ring enclosure, clearly suggests that the muons produced at or upstream of the 840 location will range out in the soil between the two enclosures and hence do not pose any radiation problem in the MI ring enclosure (it is estimated that there is about 300 ft of soil at the 840 location and about 600 ft of soil at the 833 location, projecting long the primary proton beam direction). Hence, irrespective of the location of the beam absorber viz., 833 or 840 location, the radiation arising from muons is not of concern during 8 GeV beam line commissioning.

IV. Summary

We have performed a detailed shielding assessment of the 8 GeV beam line enclosure to ensure that the shielding is in compliance with the FRCM. To meet the criteria of 24.5 ft soil equivalent shielding throughout the beam line, we have added steel shielding where necessary. Special control measures to be determined in a separate assessment will be taken in the vicinity of locations 800 to 803. The final configuration of the Radiation Safety System will preclude personnel access to the AP2 tunnel at the crossover region when beam may be transported through the 8 GeV line. A combination of an interlocked detector and entry controls have been and will continue to be utilized to limit the radiation hazard to personnel in the 8 GeV line due to beam transport in the AP2 line.

Acknowledgments

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V. A. Construction Drawings

1.	6-6-12	SC-1	8 GeV beam enclosure connection
2.	6-6-9	C-3	8 GeV beam enclosure site plan
3.	6-6-9	C-4	8 GeV beam enclosure cross section
4.	6-6-9	C-11	8 GeV beam enclosure connection finished site plan
5.	6-6-12	C-20	8 GeV beam enclosure connection finished cross section
6.	6-6-12	C-22	8 GeV beam enclosure connection: shielding steel plan and section.
7.	6-6-12	C-23	8 GeV beam enclosure connection : shielding steel sections.
8.	6-6-9	SC-13	8 GeV beam enclosure : encl. W/Exit stair 818 & 828
9.	6-6-9	SC-14	8 GeV beam enclosure :Exit stairs plan.
10.	6-6-12	SC-2	8 GeV beam enclosure connection : 8 GeV enclosure (800 to 810).
11.	6-6-12	SC-8	8 GeV beam enclosure connection : Enlarged plan @ exit stairs.
12.	6-6-9	C-5	8 GeV beam enclosure connection : Cross sections - sheet 2
13.	6-6-9	M-4	8 GeV beam enclosure connection : Enclosure HVAC plan abd sects.
14.	6-6-9	SC-7	8 GeV beam enclosure : MI8 Building alcove and labyrinth.
15.	6-6-9	SC-8	8 GeV beam enclosure : MI-8 Building hatch and stair plan.
16.	6-6-9	SC-9	8 GeV beam enclosure : MI8 sections - sheet 1.
19.	6-6-10	C-1	8 GeV /AP enclosure crossover : plan and profile.
20.	6-6-10	C-5	8 GeV /AP enclosure crossover : shielding steel.
21.	6-6-10	C-3	8 GeV /AP enclosure crossover : cross sections.

V B. Radiation Shielding Drawings

1.	9-6-6-12	C-1	MI 8 GeV Rad. Safety CB805 - CB810
2.	9-6-6-12	C-2	MI 8 GeV Rad. Safety CB803 - CB805
3.	9-6-6-12	C-3	MI 8 GeV Rad. Safety Shielding Steel - sht.1
4.	9-6-6-12	C-4	MI 8 GeV Rad. Safety Cross Sections CB805 - CB808
5.	9-6-6-12	C-5	MI 8 GeV Rad. Safety Cross Sections CB803 - CB805
6.	9-6-6-12	C-6	MI 8 GeV Rad. Safety CB803.5
7.	9-6-6-12	C-7	MI 8 GeV Rad. Safety CB804 - CB805
8.	9-6-6-12	C-8	MI 8 GeV Rad. Safety CB806
9.	9-6-6-12	C-9	MI 8 GeV Rad. Safety CB807 - CB810
10.	9-6-6-12	C-10	MI 8 GeV Rad. Safety CB809 - CB810
11.	9-6-6-9	C-1	MI 8 GeV Rad. Safety Plan & Profile CB832 to CB852
12.	9-6-6-9	C-2	MI 8 GeV Rad. Safety Plan & Profile CB810 to CB832
13.	9-6-6-9	C-3	MI 8 GeV Rad. Safety Cross Sections
14.	9-6-6-9	C-4	MI 8 GeV Rad. Safety Cross Sections
15.	9-6-6-9	C-1	MI 8 GeV Rad. Safety A/P shielding Layers AP, A & B
16.	9-6-6-9	C-2	MI 8 GeV Rad. Safety A/P shielding Layers C & D

VI. **References** (* Implies these references are included as attachments)

[1] Fermilab Main Injector Technical Design Handbook (1994).

[2] Fermilab III Design Handbook (1995).

[3]* Shielding of the West Booster Tower Building from the Radiation Arising from the Operational losses of 8 GeV proton Beam at the Booster Extraction region during Main Injector Era", C.M. Bhat and P. Martin (June 15, 1994).

[4] Fermilab Radiological Control Manual.

[5] Fermilab Main Injector Preliminary Safety Analysis Report-(1992).

[6]* Dugan Criteria " Radiation Shielding Calculations for Booster Operations with Main Injector", Memo to Vinod Bharadwaj, July 29, 1991.

[7] Ginneken, A. Van, "CASIM: Program To Simulate Transport of Hadronic Cascades in Bulk Matter", 272 1100.050.

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[10] "Computer Code EXIT2A", Regina Rameika and C. Moore, (private Communication 1996) and "A Study of Neutron Attenuation in the E-99 Labyrinth", Paul Ruffin and Craig Moore, Radiation Physics Note #9.

[11]* Fermilab Radiation Guide Tables 1, 2A, and 2B dated November 1989.

[12]* "Radiation Shielding of MI8 Beam Line", Memo by J. Lackey (Oct. 1996).

[13] "Calculations of Shielding Steel Requirements for the 8 GeV Line", by P. S. Martin and C. M. Bhat (1996).

[14] "Procedures for Application of Don Cossairt's CASIM Calculations in TM-1140 to Bulk Shielding", P. Garbincius, FERMILAB-TM-1719.

[15]* "Interlock gates for MI - 8 service building", Memo from C.M. Bhat to Phil Martin and John Anderson,(Nov. 14, 1996).

[16]* "8 GeV shielded Hatch", Memo by C. M. Bhat to Tom Pawlak, Feb. 13, 1996.

[17]* "Radiation Dose on the 8 GeV Beam-line Berm due to Sight Riser", C. M. Bhat. September 20, 1995.

[18]* "Shielding Requirements Around the Intersection of AP2 and 8 GeV Beam Lines", by C.M. Bhat (April 7, 1994).

[19]* "Radiation Level in the Intersection Region of AP2 and 8 GeV Beam-line, Due to Beam loss in the AP2 Beam-line", C.M. Bhat and P. Martin, MI Note - 0.0148, (1995).

[20]* "Temporary, Partial Transport Enclosure Shielding Assessment and Suggested Entry Controls to Permit Personnel Access to the MI-8 Enclosure During Transport Beam Operations" , Memo from Tony Leveling to R. Pasquinelli, Dated Nov. 1 1996.